Initial Effects of Reproduction Cutting Treatments on Residual Hard Mast Production in the Ouachita Mountains

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ABSTRACT: *We compared indices of total hard mastproduction (oak und hickory combined) in 20, second-growth, pine-hardwood stands under five treatments to determine the effects of different reproduction treatments on mast production in the Ouachita Mountains. We evaluated mast production in mature unharvested controls and stands under four reproduction cutting methods (single-tree selection, group selection, shelterwood, and clearcut with wildlife tree retention) during the first 6 yr after initial harvest. Mean Whitehead mastproduction indices were greater in shelter-woods und clearcuts with wildlife tree retention than in unharvestedstands 5 of the 6 yr of study, indicating individual trees in these standsproducedgreateramounts of hard mast. Stand production valuesfor the 6 yr combined indicated group selections generally produced the greatest amounts of total hard mast, probably because competing pines in the matrix were thinned and hard mast-producing tree densities were unchanged after harvest. However, wide variation in residual density of mast trees existed among stands of the same treatment. Our results indicate hard mast production can be affected by different silvicultural treatments and managers should consider the importance of residual mast production along with other objectives when determining silvicultural treatments to apply. South. J. Appl. For. 27(4):253–258.*

Key Words: Acorns, Arkansas, *Carya*, clearcut, group selection, hickories, Oklahoma, *Quercus*, single-tree selection, shelterwood, silviculture.

Hard mast is an integral component of forested ecosystems in many regions of the world and its abundance can affect both forest regeneration and wildlife that consume it. Hard mast availability can affect condition, reproduction, movements, survival, and population parameters of wildlife species that depend on it as a food source (e.g., Nixon et al. 1975, Wentworth et al. 1990, McShea and Schwede 1993).

Although numerous studies have examined hard mast production (primarily acorns), most studies have focused either on yearly variations in production or attempted to determine the causes of these yearly fluctuations (e.g., Downs and McQuilkin 1944, Sork and Bramble 1993, Koenig et al. 1994). Few studies have examined the effects of forest management on mast production other than limited studies on the effects of thinning (Harlow and Eikum 1963, Healy 1997, Perry et al., in press). We are unaware of any studies that examined the effects of different reproduction cutting treatments on hard mast production.

Recent political and environmental concerns have prompted federal and state management agencies to rely less on clearcutting and planting to regenerate pines (*Pinus* spp.) and more on alternative even (e.g., seed tree and shelterwood) and uneven-aged (single-tree and group selection) silvicultural systems (Baker 1994). In pine-dominated stands of the southeastern United States, overstory hardwoods are often retained for aesthetics, diversity, and as a source of hard mast, with oaks (*Quercus* spp.) and hickories (*Carya* spp.) being the primary producers. Because silvicultural systems that rely on natural pine regeneration appear to be a primary USDA Forest Service management approach of the future, managers need to know how different reproduction cutting methods affect residual hard mast production.

We compared indices of oak and hickory mast production among unharvested controls and four reproduction cutting treatments (single-tree selection, group selection, shelterwood,

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and clearcut with wildlife tree retention) in second-growth pine-hardwood stands. Stands were located in the Ouachita Mountains of Arkansas and Oklahoma and *were* evaluated for 6 yr following harvest.

Methods

Study Areas

Our study was conducted in west central Arkansas and east central Oklahoma throughout the Ouachita National Forest and the southern-most district of the Ozark-St. Francis National Forest (Thill et al. 1994). The Ouachita Mountains are a series of east-west ridges and valleys where elevations range from 1.52 to 853 m, mean annual precipitation ranges from 112 to 137 cm, and mean annual temperatures range from 13.9 to 16.1ºC (Skiles 1981).

We selected five late-rotation, mixed pine-hardwood stands in each of four physiographic zones (the north, south, east, and west regions) of the Ouachita Mountains, for a total of 20 stands (Baker 1994). Prior to harvest, each stand was greater than 60 yr old, 14.2-28 ha in area, located on southerly aspects, had slopes less than 20%, pine basal areas (BA) of 13.8-25.3 m^2/ha, and hardwood BA of 4.6-l 1.5 m^2/ha. For several decades prior to harvest, only custodial management (fire suppression, etc.) had occurred in these stands. Collectively, the most abundant tree species within study stands were shortleaf pine (*P. echinata),* post oak *(Q. stellata*), white *oak (Q. alba),* sweetgum *(Liquidambar styraciflua*), and hickories (Guldin et al. 1994).

Treatments

Within each of the four physiographic zones, stands that met our selection criteria were randomly assigned one of five treatments. Thus, each treatment was replicated four times in a completely randomized design (five treatments among 20 stands). Treatments consisted of an unharvested control, three partial cutting methods, and a clearcut with wildlife tree retention treatment. One unharvested control was inadvertently harvested in 1997 and was replaced with a similar stand for subsequent evaluation. Stands were harvested during the summer of 1993. Treatments were as follows:

1. Unharvested-These stands consisted of mature, second-growth, pine-hardwood stands with pine and hardwood BA similar to preharvest conditions of other treated stands (Table 1).

2. *Pine/hardwood single-tree selection-Some* pines and hardwoods were removed throughout the stand (Table 1). All hardwoods less than 15 cm dbh were felled with chainsaws.

3. *Pine/hardwood group* selection-All pines and most hardwoods were removed in openings that ranged from 0.04 tol.9 ha and represented 6-14% of the total stand area. Residual hardwood BA in group openings was 1. 1–2.3 m^2/ha (Table 1). Pine BA in the stand surrounding these openings was reduced to 16.0-18.4 m^2/ha and no hardwoods were harvested. Within openings, all hardwoods less than 15 cm dbh were chainsaw felled but no hardwoods were felled outside openings.

4. *Pine/hardwood shelterwood*—From 49 to 99 of the largest pines and hardwoods per hectare were retained (Table I). All other pines and hardwoods were harvested or felled.

5. *Clearcut with wildlife tree* retention-All merchantable pines and hardwoods (except a few scattered hardwoods retained for wildlife den and mast trees) were harvested (Table 1). All nonmerchantable trees (except retained wildlife trees) were injected with Garlon® herbicide (Baker 1994).

All stands contained ephemeral or intermittent streams that typically flow only during high runoff events. Unharvested buffer strips or greenbelts (typically 10 m on both sides of ephemeral or intermittent streams) wereretained for watershed protection. Total percent of each stand retained as greenbelt ranged from 4 to 20% and averaged 10.9% across all 16 harvested stands. Oaks and hickories in greenbelts were not included in the analysis.

Mast Production Estimates

Each stand was evaluated yearly in late August 1994-1999. Prior to timber harvest, 4 to 9 (depending on stand size and shape), parallel, 15-m-wide belt transects were established in each stand (Thill et al. 1994). Within these belt transects, all oaks ≥20 cm dbh and all hickories 215 cm dbh

Table 1. Range and mean (± SE) total basal area (BA; m^2/ha) of pines and hardwoods >9.1 cm, BA of potential mast-producing trees (oaks ≥ 20.0 cm and hickories ≥ 15.0 cm dbh), and density of potential mast-producing trees the fourth year after harvest for 20 stands under five treatments in the Ouachita Mountains of Arkansas and Oklahoma.

	Total BA		Oak/hickory BA		Oak/hickory density (trees/ha)	
Treatment	Range	Mean	Range	Mean	Range	Mean
Unharvested	26.0–33.0	30.4 ± 1.7	1.7-5.5	3.1 ± 0.9	46.0-70.7	58.2 ± 5.6
Single-tree selection	15.2-18.5	16.9 ± 0.8	1.6–4.2	2.9 ± 0.5	23.1-65.5	38.6 ± 9.3
Group selection	16.7-23.9	20.2 ± 1.5	1.2-8.9	3.4 ± 1.1	36.8-1 18.9	70.3 ± 17.3
Openings	1.1-6.6	4.4 ± 1.2	1.6–4.6	3.4 ± 0.7	23.7-59.0	43.1 ± 7.8
Matrix	18.1-25.3	22.2 ± 1.5	1.1-9.8	3.4 ± 2.1	34.6-148.0	78.8 ± 24.3
Shelterwood	9.5–13.5	11.8 ± 0.9	1.7-3.7	2.6 ± 0.4	16.6-30.1	23.9 ± 3.4
Clearcut with wildlife tree retention	0.8-2.5	I.4 ± 0.4	0.8-1 .3	1 .o ± 0.	8.1-14.8	10.7 ± 1.5

were evaluated for mast. We selected these minimum sizes based on personal observation of trees that produce mast. Transects were 30 to 95 m apart, ran perpendicular to the slope of the stand, and were greater than 50 m from stand boundaries. Total transect length varied from 1,395 to 1,440 m among stands. Large differences existed in the density of residual mast trees among treatments. Therefore, to make tree sample sizes more equal among treatments, we sampled only a randomly selected portion of the total transect area in stands with high mast tree densities (unharvested, group selection matrix areas, and single-tree selection stands). From 1995 to 1999, sampling area was increased by an average of 23% over those of 1994 to increase the overall number of trees sampled. Thus, total area sampled in each stand during the study was 0.99-1.28 ha in unharvested stands, 0.92-I .42 ha in single-tree selection stands, 1.15–1. 19 ha in group selection stands, 1.80-2.16 ha in shelterwood stands, and 2.07-2.14 ha in clearcut with wildlife tree retention stands.

We estimated the production of each oak or hickory using the visual mast survey method described by Whitehead (1969) and Perry and Thill(l999). The Whitehead index is derived by visually estimating the percent of a tree's crown producing nuts, the percent of twigs with nuts, and the average number of nuts per twig. This method yields an index ranging from 0 (no production) to 10 (bumper crop), and is commonly used to compare relative mast production among trees (e.g., Wentworth et al. 1990, Ford et al. 1997). Although different observers conducted the surveys some years, all observers underwent training prior to conducting the surveys to ensure standardized criteria were used in their mast evaluations (Perry and Thill 1999).

Whitehead indices estimate average production per tree in each stand but do not account for differences in mast tree density among areas or differences in sample size among stands. Therefore, we adjusted the Whitehead scores to create a new index (density adjusted index or DA index) that reflected total mast production per stand. To compensate for differences in mast tree density and sampling area among stands, we multiplied the mean Whitehead index for each stand by the density (trees/ha) of potential mast-producing trees in that stand. This density adjusted index was used as a measure of total stand production and ranged from 0 to a high of around 450 per stand.

Oak and hickory species composition differed among stands because of differences in site, past management, and the imposed treatments. Consequently, post oaks were the dominant residual oak in some stands but were absent in others whereas white oaks were the dominant oak in most stands. No species of the red/black oak group (subgenus *Erythrobalanus*) was abundant in all stands. *Erythrobalanus* oaks included in our analysis were northern red oak *(Quercus rubra*), black oak *(Q. velutina),* southern red oak (*Q. falcata*), and blackjack oak *(Q. marilandica*). Study stands contained two species of hickory: mockernut *(Carya tomentosa*) and black (C. *texana*). Because mast tree species composition differed among stands, and because our primary objective was to compare total mast production (available for wildlife) among different reproduction cutting methods, data for all species were pooled for analysis of treatment effects.

Analyses

We compared yearly Whitehead production indices among physiographic zones and among treatments using one-way ANOVA on ranks and Duncan's Multiple Range Test (MRT) (SAS Institute, Inc. 1988); Whitehead indices could not be normalized. We compared DA index treatment means and DA index physiographic zone means for each year using one-way ANOVA and Duncan's MRT. Density adjusted index values were normal and variances were homogeneous following a log transformation ($\ln[x + I]$).

To compare differences among treatments over all 6 yr of study, we calculated a mean DA and Whitehead index value for each stand from the 6 yr of study, then calculated treatment and physiographic zone means from these averaged values. For these comparisons, we used one-way ANOVA and Duncan's MRT; Whitehead scores were ranked and DA values were log transformed ($\ln[x + 1]$). For group selection stands (comprised of two distinct stand conditions) we computed weighted indices based on the percentage of area in openings and the surrounding matrix.

Results

Total number of trees evaluated for mast in all 20 stands combined ranged from 667 in 1994 to 966 in 1999 (Figure 1). Yearly sample sizes differed due to an increase in sample area, natural and logging-related mortality, mortality of herbicide-injected trees in clearcuts with wildlife tree retention (which can take years), and smaller trees attaining our minimum dbh for measuring due to vigorous growth following release. Over the 6 yr study, the total number of trees sampled in each stand averaged (±SE) 19.1 ± 1.5 in clearcuts with wildlife tree retention, 34.5 ± 2.7 in shelterwoods, 35.5 ± 1.4 in single-tree selections, 69.2 ± 6.5 in group selections, and 58.4 ± 3.1 in unharvested stands.

There were no differences in Whitehead or DA indices among physiographic zones by species group (red-black oaks, white-post oaks, and hickories) or for all species combined, in any year of evaluation. For all years combined, there were also no differences in Whitehead or DA indices among physiographic zones by species group or for all species combined.

When data were pooled across treatments, Whitehead indices (for species groups and all species combined) fluctuated widely among years (Figure 1); this is typical of oak and hickory production throughout their range (e.g., Downs and McQuilken 1944, Goodrum et al. 197 1, Christisen and Kearby 1984). Relatively low mast production in 1994, 1996, and 1998 was each followed by a relatively good production year. Based on physiographic zone analysis, during poor years, mast was generally poor throughout the region and not isolated to individual physiographic zones.

Differences Among Treatments

Whitehead mast production indices differed ($P < 0.05$) among treatments 5 of the 6 yr of study (Table 2). Individual

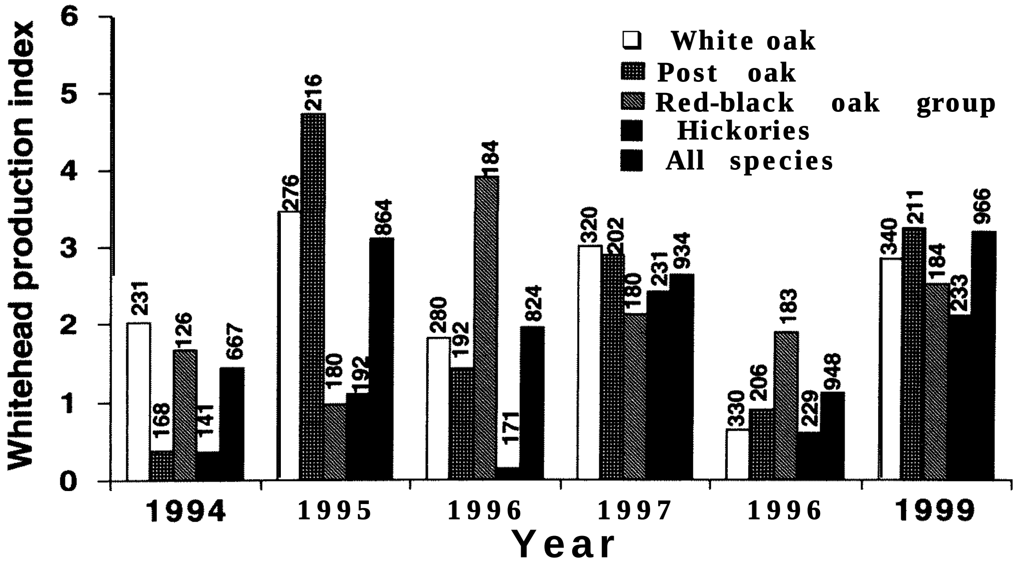

Figure 1. Whitehead hard mast production indices for five species/species groups throughout the Ouachita Mountains of Okalahoma and Arkansas from 1994 to 1999 in 20 stands under five treatments (unharvested, single-tree selection, group selection, shelterwood, and clearcut with wildlife tree retention). Numbers above columns indicate total number of trees surveyed.

trees produced more mast in stands with lower BA than trees in stands with higher BA. During each year, residual trees in clearcuts with wildlife tree retention and shelterwoods had higher Whitehead indices than individual trees in unharvested stands. For all years combined, residual trees in clearcuts with wildlife tree retention had the highest Whitehead indices and trees in unharvested stands had the lowest; single-tree selection and group selections stands did not differ but were significantly lower than shelterwood stands.

Density adjusted indices differed ($P < 0.05$) among treatments during 2 (1995 and 1999) of the 6 yr (Table 3). Generally, clearcuts with wildlife tree retention (with low mast-tree densities but high individual tree production) and unharvested stands (with high mast-tree densities but low individual tree production) had the lowest DA indices. Single-tree selection and group selection stands, which had undergone moderate harvesting, had the highest DA values. For all years combined, DA values were highest in group selection stands whereas clearcuts with wildlife tree retention and unharvested stands had the lowest DA values; single-tree selection and shelterwoods were intermediate in production.

Over the 6 yr period, the DA index coefficient of variation among stands of the same treatment was lowest in clearcuts with wildlife tree retention and shelterwoods and highest in group selection and unharvested stands (mean CV for clearcuts with wildlife tree retention = 40.5%, shelterwoods = 53.7%, single-tree selection = 79.3%, group selection = 87.6%, and unharvested = 84.5%). Thus, variation in production among stands of the same treatment was greatest in stands with high residual BA and lowest among stands with low residual BA.

Discussion

Other studies have established aclearrelationship between basal area and seed production in pines (e.g., Croker 1952, Bilan 1960, Godman 1962). However, few studies have demonstrated this relationship in oaks and hickories. Perry et al. (in press) reported a linear relationship between total

Table 2. Mean (±SE) Whitehead hard mast production indices for oaks and hickories among five silvicultural treatments, by year and all years combined, and ANOVA test values for 20 stands in the Ouachita Mountains of Arkansas and Oklahoma.

	Treatment						
Year	Unharvested	Single-tree selection	Group selection	Shelterwood	Clearcut with wildlife tree retention	F	P
1994	*0.7^b ± 0.3	0.7^b ± 0.4	0.7^b ± 0.4	2.1" ± 0.8	2.9" ± 0.4	4.46	0.01
1995	0.6^b ± 0.3	3.4" ± 0.1	2.7" ± 0.6	4.0" ± 0.7	4.9" ± 0.9	4.65	0.01
1996	0.1' ± 0.2	1.0b^c ± 0.4	1.2^{bc} ± 0.4	2.2^{ab} ± 0.6	4.2" ± 0.7	6.37	<0.01
1997	1.3 ± 0.3	2.8 ± 0.7	2.4 ± 0.8	3.1 ± 0.4	3.5 ± 0.4	2.36	0.10
1998	0.4' ± 0.2	0.4^c ± 0.1	1.3^b ± 0.4	1.1^b ± 0.3	2.4" ± 0.3	8.15	co.01
1999	0.8" ± 0.2	3.0^b ± 0.2	2.9^b ± 0.3	3.8^b ± 0.8	5.4" ± 0.6	10.14	co.01
All years	0.8^d ± 0.2	1.9^c ± 0.2	1.9' ± 0.2	2.7^b ± 0.2	3.9" ± 0.3	32.66	<0.01

* Within rows, means followed by the same letter were not different ($P > 0.05$) using one-way ANOVA (df = 4,15) on ranks and Duncan's Multiple Range Test.

Table 3. Mean (±SE) density adjusted (DA) hard mast production indices for oaks and hickories among five silvicultural treatments, by year and all years combined, and ANOVA test values in 20 stands in the Ouachita Mountains of Arkansas and Oklahoma.

	Treatment						
Year	Unharvested	Single-tree selection	Group selection	Shelterwood	Clearcut with wildlife tree retention	F	P
1994	27.9 ± 11.4	33.5 ± 24.3	62.5 ± 48.8	32.5 ± 7.2	26.9 ± 5.6	0.41	0.80
1995	*32.2^{b} ± 20.9	132.8" ± 28.8	187.1" ± 51.0	89.7" ± 33.5	59.0^{ab} ± 15.0	3.99	0.02
1996	38.0 ± 17.8	59.7 ± 30.3	78.6 ± 34.0	38.9 ± 6.6	40.3 ± 6.9	0.57	0.69
1997	77.2 ± 20.8	123.7 ± 50.2	200.5 ± 102.1	71.1 ± 11.7	36.9 ± 5.0	0.98	0.45
1998	28.3 ± 12.8	14.2 ± 4.9	92.1 ± 29.1	27.8 ± 10.3	26.2 ± 5.6	2.11	0.13
1999	48.9^{c} ± 14.1	113.8^{ab} ± 20.2	232.1^{a} ± 73.7	98.9^{bc} ± 31.0	59.8^{bc} ± 13.9	5.21	<0.01
All years	42.1^{b} ± 14.1	79.6^{ab} ± 24.5	142.2" ± 49.8	59.8^{ab} ± 11.0	41.5^{b} ± 7.2	3.39	0.04

* Within rows, means followed by the same letter were not different ($P > 0.05$) using one-way ANOVA ($df = 4,15$) on log-transformed ($\ln[x + 1]$) data and Duncan's Multiple Range Test.

overstory basal area and Whitehead indices for white and post oaks during five consecutive years and during 2 of 5 yr for hickories. Using seed traps, Healy (1997) found individual northern red oaks in New England stands thinned to 50% stocking produced more acorns than trees in unthinned stands, and Paugh (1970) found individual northern red oaks in heavily thinned stands produced more mast than trees in unthinned stands.

Our results indicate partial harvesting of mature pine-hardwood stands increased indices of hard mast production for individual residual trees. Individual trees in harvested stands (regardless of treatment) produced more mast than trees in unharvested mature second-growth pine-hardwood stands. Furthermore, individual trees in stands that had undergone substantial reductions in BA (clearcuts with wildlife tree retention and shelterwoods) produced greater amounts of mast than trees in stands with less substantial reductions in BA (single-tree selection and group selection stands). Residual trees in clearcuts with wildlife tree retention produced great quantities of mast compared to individual trees in other treatments and these relatively isolated trees probably provide excellent areas of concentrated mast for wildlife. Although reductions in basal area clearly increased production of individual trees, reducing the density of mast producing trees may be a drawback. Others have suggested that reducing BA increases the production of individual trees but decreases the overall stand production (Harlow and Eikum 1963, Minckler and McDermott 1960). Our results suggest group selection stands generally had higher stand-level mast production indices than other treatments, especially the clearcuts with wildlife tree retention and unharvested controls. The higher DA values for the group selection treatment were likely because hardwoods were not harvested in the matrix (which comprised approximately 90% of the stand area) but a portion of their competition (overstory pines) was removed during harvesting in 1993. This reduction in pine density apparently was enough to increase mast production of the residual hardwoods. Thus, partial or complete harvesting of species other than mast producers should increase the overall mast production in stands with heterogeneous species composition.

Our results indicated little difference in stand-level production indices among treatments other than group selection. Although total overstory residual BA among stands of the same treatment was similar, wide variation in residual mast tree densities among stands of the same treatment probably reduced our ability to discern differences among treatments. This was especially apparent in group selection stands where mast tree densities ranged from 37.8 to 118.9 trees/ha. This variation in mast tree density within some treatments was primarily a result of differences in stands prior to harvest. Because no hardwoods were removed from matrix areas of group selection stands, mast-tree density differences among these stands were a result of preharvest conditions. However, some density differences among stands within the same treatment may have resulted from differences in how harvest prescriptions were implemented. Original prescriptions called for retained hardwood BA (m^2/ha) of 1.1-4.6 in single-tree selection stands, 1 .l-3.4 in shelterwoods, and 0.5-l. 1 in clearcuts with wildlife tree retention. Within these limits, a two or three-fold difference in residual hardwood BA could exist among stands of the same treatment.

It should be noted that this study began the first year after initial harvest. Uneven-aged treatments (single-tree and group selection) had not yet developed an uneven-aged structure. With these treatments, cutting cycles are typically conducted on a 10 yr interval. Therefore, it is unknown how additional harvest entries will affect future mast production. With 10 yr entries in group selection stands whereby 10% of the stand is harvested in new openings, these stands will have more young trees in the future. Furthermore, additional entries in single-tree selection stands will result in fewer overstory mast trees and more midstory and understory mast trees. It is doubtful these younger midstory trees will produce significant mast; however, the continuously maintained overstory should produce mast into perpetuity in single-tree selection stands.

Objectives to consider when implementing silvicultural treatments include regeneration goals, growth and yield targets, desired understory responses, and the effects on selected wildlife species. Our results indicate different reproduction treatments can affect residual hard mast production and managers should consider residual hard mast production along with other objectives. Based on our findings, hard-mast producing trees respond to partial harvesting by increasing production, and overall production within stands is generally increased by light cutting. Furthermore, reproduction treatments that minimize the removal of mast species while removing competing species can increase the overall mast production within stands.

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